Computer algebra system calculators: Gender issues and teachers' expectations

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In this paper we present findings from two studies focusing on computer algebra system (CAS) calculators. In Victoria, Australia, it is currently mandatory for students to use graphics calculators in some grade 12 mathematics examinations. Since 2001, a pilot study has been conducted involving Victorian Certificate of Education (VCE) students using CAS calculators instead of graphics calculators. From 2006–2008 the CAS calculator will be optional; from 2009 it is expected to replace the graphics calculator. The first study described here involves an exploration over a three-year time frame, 2002–2004, of male and female students' results in the grade 12 Mathematical Methods subject in which students used graphics calculators and small numbers of students in the pilot study, Mathematical Methods (CAS) subject, who used CAS calculators. The findings indicated a widening of the gender gap in performance favouring males. In the second study, teachers' views of the likely impact of the widespread use of CAS calculators were examined. Teachers were generally positive about the introduction of the CAS calculators and their impacts on teaching, student learning, and the curriculum. The implications of the findings of the two studies are discussed.

Context and background of the research

The studies described in this paper were based in Victoria, Australia. In Victoria, guidelines for the use of technology in the mathematics curriculum are provided by the Victorian Curriculum and Assessment Authority (VCAA). The curriculum document for the 11 compulsory years of schooling (P-grade 10) is the Curriculum and Standards Framework II [CSFII] (Victorian Board of Studies [VBOS], 2000). The sensible use of technologies including scientific, graphics and CAS calculators is advocated. for "concept development, as well as in technology-assisted approaches to problem solving, modelling and investigative activities" (VBOS, 2000, p. 8). The Victorian Certificate of Education [VCE] covers grades 11 and 12. One of the outcomes stipulated for VCE Mathematics is "the effective and appropriate use of technology to

produce results which support learning mathematics and its application in different contexts” (VCAA, 2005a, p.7).

For the years 2002–2004, the years of interest in the studies reported here, there were three grade 12 VCE mathematics subjects offered: Specialist Mathematics (the most challenging), Mathematical Methods (a prerequisite for most mathematics and science-related tertiary courses), and Further Mathematics (the least demanding option). During these years, graphics calculators were mandated for the examinations in Mathematical Methods. Running parallel, and containing considerable amounts of common material to Mathematical Methods, was Mathematical Methods (CAS), a pilot project in which a small number of students from participating schools used CAS instead of graphics calculators.

In December 2003, a consultation paper for the future assessment program for VCE mathematics in 2006 and beyond was published by the VCAA (2003). For the accreditation period commencing in 2006, all students would be able to study Mathematical Methods (CAS) or Mathematical Methods. Various models for the two examinations for each VCE subject offered were mooted. More recently:

It has been foreshadowed by the VCAA that the two studies [Mathematical Methods and Mathematical Methods (CAS)] will merge into a single CAS enabled study in the accreditation period starting 2010. To this end and to support the development of CAS skills and teaching approaches, it has been foreshadowed that examiners in Mathematical Methods and Specialist Mathematics will assume student access to a CAS for Examination 2 in 2009. (VCAA, 2005b, p.12).

In the intervening years 2006–2008, there will be “a common technology-free Examination 1 for Mathematical Methods and Mathematical Methods (CAS)” (VCAA, 2006), and a second examination requiring the use of a graphics calculator for Mathematical Methods and a CAS for Mathematical Methods (CAS).

The Mathematical Association of Victoria [MAV] prepared a submission (MAV, 2004) in response to the VCAA (2003) consultation paper. As well as a range of other issues, the MAV raised equity concerns with respect to access, affordability and gender. In particular, the MAV was concerned whether the proposed introduction of CAS technology would increase inequities in participation and achievement in VCE mathematics. Based on the findings of a literature review, it was claimed that the introduction of CAS into mathematics “is likely to favour males and could lead to lower achievement and enrolments of girls in VCE mathematics” (MAV, 2004, p.9). While some positive findings from the Mathematical Methods (CAS) pilot study were recognised, the MAV noted that the participating schools may be considered atypical.

The two research studies reported in this paper set out to examine:

Study 1: Participation and achievement comparisons for males and females in Mathematical Methods and Mathematical Methods (CAS) for the three-year duration of the CAS pilot study: 2002–2004

Study 2: Views of a group of male and female teachers not involved in the CAS pilot study about the likely effects of imminent introduction of CAS calculators into grade 12 mathematics

Previous research

Internationally, there is an apparent dearth of research on the impact of CAS calculators on students' mathematics learning. Hence Australian research is the main focus of this brief review of relevant literature.

Several articles on aspects of the Mathematical Methods (CAS) pilot study have been published with generally favourable findings for CAS using students. Three teachers in the pilot study reported that using CAS had influenced their teaching of mathematics and their students' learning, understanding, thinking and enjoyment of the subject (Garner, McNamara, & Moya, 2003). Garner (2005), a teacher involved in the pilot study, found that CAS using students were confident to explore unfamiliar functions and were able to transfer effortlessly between numeric, graphic, and symbolic solutions. Evans, Norton, and Leigh-Lancaster (2004) examined student performance on common questions found on the 2003 examinations for VCE Mathematical Methods and Mathematical Methods (CAS); it was concluded that the CAS cohort generally scored better on these items. Pierce, Herbert, and Giri (2004) examined a first year university setting in which students were encouraged to use CAS calculators and found that although lectures were carefully planned and ready access to CAS calculators was provided for all tasks, students did not exploit the capabilities of the CAS calculators. For effective CAS use, the authors concluded that teachers needed to provide technical assistance, convince students of the effectiveness of CAS, and reward its use in assessment.

Gender issues were a focus of a large-scale study of Norwegian Engineering students' views of computer-based CAS (e.g., Maple, Mathematica) (Hornaes, & Royrvik, 2000). Based on self-report survey data from 1771 students, no gender differences were found for expected mathematics achievement. However, males were found to hold more positive views than females about the usefulness of CAS generally as well as for understanding mathematics.

While research has been conducted on the use of CAS calculators for mathematics learning with generally favourable outcomes, no Australian studies appear to have considered gender issues and none appears to have explored the views of teachers not already using CAS calculators with their students. In the studies reported in this article, these two missing dimensions have been examined.

Research study 1: Mathematical Methods (CAS) and gender differences in mathematics achievements

Methods: Sample, instrument and analyses

The raw data analysed in this study were derived from a public domain source — the VCAA website (http://www.vcaa.vic.au). The VCAA website includes statistical information about enrolment numbers in the VCE and results by year and gender for all grade 12 subjects. Based on the raw data found on the website, several statistics were derived with respect to the subjects Mathematical Methods and Mathematical Methods CAS including:

- for all students, and by gender, percentage enrolments in terms of respective VCE cohort sizes, and male to female ratios in these enrolment data
- for all students, and by gender, percentages of students obtaining the top three grades: A+, A, and B+, and male to female ratios for these achievement data.

Results

For the years 2002–2004, VCE enrolments overall and in the subjects Mathematical Methods and Mathematical Methods (CAS), as well as several derived statistics including male to female ratio (M:F) and percentage enrolments in the subjects of interest, are shown in Table 1.

Table 1. Enrolments in VCE, Mathematical Methods, and Mathematical Methods (CAS) by gender, 2002–2004.

Enrolments	Male	Female	Total	M:F
	2002			
All grade 12 VCE students	22977	26554	49531	0.87
Mathematical Methods	9586	8318	17904	1.15
Mathematical Methods (CAS)	25	53	78	0.47
VCE students taking Mathematical Methods (%)	41.72	31.32	36.15	1.33
VCE students taking Mathematical Methods (CAS) (%)	0.11	0.20	0.16	0.55
	2003			
All VCE students	23468	26409	49877	0.89
Mathematical Methods	9797	8349	18146	1.17
Mathematical Methods (CAS)	181	90	271	2.01
VCE students taking Mathematical Methods (%)	41.75	31.61	36.38	1.32
VCE students taking Mathematical Methods (CAS) (%)	0.77	0.34	0.54	2.26
	2004			
All VCE students	23543	26432	49975	0.89
Mathematical Methods	9769	8216	17985	1.19
Mathematical Methods (CAS)	247	151	398	1.64
VCE students taking Mathematical Methods (%)	41.49	31.08	35.99	1.33
VCE students taking Mathematical Methods (CAS) (%)	1.05	0.57	0.80	1.84

The data in Table 1 reveal that for all three years:

- there were more females than males enrolled in the VCE;
- just over one third of all VCE students (approximately 36%) were enrolled in one or other of the two Mathematical Methods subjects;
- higher proportions of males than females were enrolled in Mathematical Methods (e.g., M:F = 1.15 in 2002); the M:F ratios were even higher when compared to the relative enrolment numbers by gender in the VCE (e.g., M:F = 1.33 in 2002); and
- small numbers of students with varying M:Fs in the subject Mathematical Methods (CAS), but with numbers increasing over time.

One way in which the VCE results are reported is to give separate grades, ranging from A+ through to E+ (as well as UG for ungraded results) for each of the three tasks comprising the final assessment of each subject. For the two Mathematical Methods subjects, the three tasks in the years 2002–2004 included: a school-assessed set of tasks given an overall grade; one multiple-choice and short answer examination; and a second examination involving extended solution questions (examinations can be downloaded from http://www.vcaa.vic.au). For each year and for each assessment task, the within gender frequencies and percentages of students obtaining the top three grades — A+, A, and B+ — are shown in Table 2. The shaded M:F ratios are those for which a higher percentage of males than females received the particular grades; bolded ratios indicate the subjects for which the M:F ratios were higher.

The data in Table 2 indicate that:

- in each year, for each subject, and for each assessed task, a higher percentage of males than females achieved the grade A+
- without exception, the M:F ratios were higher for the A+ grades in Mathematical Methods (CAS) than in Mathematical Methods
- in general, the M:F ratios were also higher for Mathematical Methods (CAS) than Mathematical Methods for all other grades for most assessment tasks in most years.

As noted earlier, the numbers enrolled in the Mathematical Methods (CAS) pilot study over the years 2002–2004 were quite small. However, the trends noted above send cautionary warnings about the potential for the widening of the gender gap favouring males at the very top end of achievement when CAS calculators are used in high stakes assessment.

Research study 2: Teachers' views of the impact of CAS calculators on teaching, student learning, and the curriculum

Methods: Sample, instrument and analyses

A survey instrument aimed at exploring teachers' current views on calculators for the teaching of mathematics was used. Items tapping biographical data (e.g., gender, age) were also included. The final question on the survey was open-ended and participants were asked to provide their views on the follow-

Table 2. Mathematical Methods and Mathematical Methods (CAS) results at top three achievement levels, by gender, 2002–2004.

	Mathematical Methods					Mathematical Methods (CAS)				
	Male		Female		M:F[2]	Male		Female		M:F
	N	%[1]	N	%		N	%	N	%	
Grade	2002									
Task 1 (school-assessed)										
A+	1853	19	1448	17	1.12[3]	5	20	8	15	**1.33**[4]
A	2030	21	2148	26	**0.81**	4	16	14	26	0.62
B+	1698	18	1610	19	0.95	7	28	8	15	**1.87**
Examination 1										
A+	1159	12	838	10	1.20	4	16	4	8	**2.00**
A	1101	12	1046	13	**0.92**	2	8	7	13	0.62
B+	1316	14	1170	14	1.00	4	16	7	13	**1.23**
Examination 2										
A+	1063	11	580	7	1.57	4	16	5	9	**1.78**
A	1171	12	1025	12	1.00	5	20	7	13	**1.54**
B+	1245	13	1201	15	**0.87**	3	12	16	30	0.40
	2003									
Task 1 (school-assessed)										
A+	1765	18	1324	16	1.13	32	18	10	11	**1.64**
A	2031	21	1982	24	**0.88**	38	21	24	27	0.78
B+	1691	17	1654	20	**0.85**	29	16	23	26	0.62
Examination 1										
A+	1162	12	883	11	1.09	20	11	8	9	**1.22**
A	1297	14	1096	13	1.08	23	13	10	11	**1.18**
B+	1406	15	1268	16	0.94	30	17	14	16	**1.06**
Examination 2										
A+	1058	11	683	8	1.38	47	26	16	18	**1.44**
A	1207	13	1023	13	**1.00**	31	17	29	32	0.53
B+	1256	13	1091	13	1.00	33	19	7	8	**2.38**
	2004									
Task 1 (school-assessed)										
A+	1747	18	1261	15	1.20	42	17	20	13	**1.31**
A	2003	21	1939	24	0.88	57	23	28	19	**1.21**
B+	1792	18	1672	20	**0.90**	43	17	31	21	0.81
Examination 1										
A+	1102	12	793	10	1.20	35	14	16	11	**1.27**
A	1306	14	1030	13	1.08	40	17	19	13	**1.31**
B+	1512	16	1394	17	0.94	43	18	24	16	**1.13**
Examination 2										
A+	1013	11	593	7	1.57	33	14	12	8	**1.75**
A	1074	11	874	11	1.00	34	14	20	14	1.00
B+	1168	12	1073	13	0.92	40	17	21	14	**1.21**

1 Within gender cohort percentages. Gender cohort sizes found in Table 1.
2 Male to female ratio (M:F) = percentage males : percentage females.
3 Shaded ratios – when M:F>1 i.e. greater % males than females.
4 Bolded M:F ratio — higher M:F ratio for the two subjects.

ing statement about the imminent introduction of CAS calculators to the VCE mathematics program:

> From 2006 onwards students will be able to use CAS (Computer Algebra Systems) calculators in VCE Mathematics examinations. Please describe in your own words the impact you think CAS calculators will have on: your teaching, student learning, and curriculum.

Separate spaces were provided for teachers to answer about each of three dimensions of interest: teaching, student learning, and curriculum.

The surveys were sent to teachers of grades 10–12 mathematics in 10 secondary schools in the metropolitan areas of Melbourne, Victoria. Forty-seven (male [M] = 25; female [F] =22) of the 116 surveys sent out were completed and returned, representing a return rate of just over 40%. It is acknowledged that the participating schools were not fully representative of the profile of Victorian schools. As a consequence, the results and their implications are treated tentatively.

Of the 47 participating teachers, 38 teachers provided responses to the question, although not all wrote responses to each of the three categories. In the results section below, only percentage responses in the various sub-categories are noted.

The qualitative responses to the open-ended item were analysed manually using a grounded approach (Strauss & Corbin, 1988) to identify common themes. The data were also analysed by teacher gender and by age grouping. Some interesting patterns and trends were noted.

Results

In general, teachers tended to respond positively to the introduction of CAS calculators in each category: teaching (positive: 68%, negative: 32%), student learning (positive: 65%, negative: 35%) and curriculum (positive: 70%, negative: 30%). Interestingly there was a pattern in the response patterns across the three categories; teachers tended to respond positively (or negatively) about the impact of CAS calculators in all three categories: teaching, student learning, and curriculum.

The responses frequencies by gender are shown in Table 3.

Table 3. Percentage frequencies of responses in each category by gender.

	Teaching		Learning		Curriculum	
	Positive	Negative	Positive	Negative	Positive	Negative
Male	65%	35%	63%	37%	65%	35%
Female	72%	28%	67%	33%	59%	41%

In Table 3 it can be seen that the male and female teachers' responses were generally positive about the introduction of CAS calculators. The response patterns were similarly distributed with a slightly higher proportion of females than males responding positively in the categories of teaching and learning; and a slightly higher proportion of males positive about the impacts on the curriculum. The sample sizes were too small, however, to make any definitive conclusions about any real differences in male and female responses.

By age grouping, some interesting patterns emerged. In general, younger (<35 years, $n = 8$) and older (>45 years, $n = 23$) teachers were more positive about the potential effects of CAS calculators (≥60% support in each category) than the 35–45 year-olds (n=16) (≤60% support in each category). To find that younger teachers would be more enthusiastic about technology was not unexpected. However, finding that older teachers were supportive was surprising and seemed to fly in the face of conventional expectations that older professionals are unlikely to support change.

Response categories and sub-categories

Within each of the three categories — teaching, student learning, and curriculum — the teachers' responses were examined and sub-categories developed. Responses were further categorised as positive or negative. The results are shown in Table 4. It should be noted that Ball and Stacey (2005) definition of judicious use of technology was adopted: when a student "routinely considers whether it is or is not efficient to use technology to solve a problem, not reaching for the technology when a little thought can quickly give an answer" (p. 4).

Table 4. Perceived positive and negative responses about CAS calculators by category and sub-category.

Positive comments					
Teaching		Student learning		Curriculum	
Judicious use	1	Judicious use	2	Judicious use	2
Syntax	1	Syntax	1	Syntax	1
Technology	5	Technology	3	Technology	2
Mathematical reasoning	9	Mathematical reasoning	6	Mathematical reasoning	7
Differentiated curriculum	1	Differentiated curriculum	2	Differentiated curriculum	2
Professional development	2	Professional development	0	Professional development	0
Negative comments					
Teaching		Student learning		Curriculum	
Technology	5	Technology	3	Mathematical reasoning	3
Preparation time	1	Mathematical reasoning	3	Fear of change	3
Fear of change	3	Differentiated curriculum	2		

As can be seen from Table 4, there were more positive than negative comments in each category — teaching, student learning, and curriculum — and more sub-categories were derived for the positive than for the negative responses:

- Teaching: 19 positive (6 sub-categories), 9 negative (3 sub-categories);
- Student learning: 14 positive(6 sub-categories), 8 negative(3 sub-categories); and
- Curriculum: 14 positive (6 sub-categories), 6 negative (2 sub-categories).

An overview of the key issues raised by teachers within each of the three categories, with pertinent, representative examples of positive and negative comments, is presented below.

Teaching

Teachers seemed to believe that their teaching practice and pedagogy would benefit from the introduction of CAS calculators. With respect to the most frequent sub-categories of responses, several (9) felt that CAS calculators would enable them to teach mathematical concepts with a greater emphasis on meaning (mathematical reasoning). One teacher wrote:

> Teaching will change — students will be able to do more complicated questions involving more general solutions.

Five teachers considered the appropriate use of the technology important. Consistent with Flynn, Berenson and Stacey (2002) who asserted that careful consideration needs to be given to the balance between by-hand and by-CAS procedures, one teacher noted:

> We will need to emphasise by hand as well as technology based solutions.

Of the teachers who expressed negative views, three seemed to fear change, for example:

> Difficult to assess how much emphasis to place on manual skills versus calculator skills.

One teacher claimed he would not teach VCE if CAS calculators became a reality, and several (5) expressed the view that the technology would dominate:

> Perhaps a greater use/reliance on calculator.

Student learning

A majority of teachers felt that student learning would be enhanced by the introduction of CAS calculators. Some (6) felt that mathematical reasoning would be enhanced, for example:

> Require students to have higher order thinking skills.
> [Students would need to] understanding at a higher level.

The need to learn to use the CAS calculator judiciously (2) and to use appropriate syntax (1) were also considered important. This was consistent

with Pierce and Stacey's (2002) assertion that "the fundamental thinking involved in symbol sense is important regardless of the level of technology that is used, but it assumes special relevance when we consider algebra with CAS" (p. 622). CAS calculators were also considered to have the potential for teachers to meet individual learning needs across the achievement range (differentiated curriculum, n=2), for example:

> Gives weaker students more confidence.
>
> Allows more students to complete procedures without manipulation getting in the way.

On the negative side, a few teachers were concerned that "students [would] tend to be led by the calculator" and that much time would be spent learning the technology rather than on mathematical concepts (technology, $n = 3$), for example:

> [The CAS calculator] will not advantage them. Learning will lack meaning.

Others (3) felt that less emphasis would be placed on understanding and mathematical reasoning, for example:

> [Students would have] less understanding but greater success at getting the correct answer.
>
> Are they learning a concept or how to use the calculator?

Some (2) felt that weaker students would be unable to cope with the complexity of the technology.

Curriculum

Teachers were generally positive about perceived curriculum changes as a consequence of introducing CAS calculators, reflecting beliefs that there would be more opportunity for the development of mathematical reasoning skills (7). It was believed that greater emphasis would be placed on problem solving and investigative work, for example:

> More analytical than computational.
>
> Less basic skills, more problem-solving.
>
> Opportunity to explore aspects of the curriculum such as modelling.

One teacher felt that the content would not change but that "methodology and assessment" would be affected. Emphasis on judicious use of calculators (2) and more opportunities to cater for a wider achievement range (2) were other positive curriculum changes envisaged.

Negative views on curriculum effects included some teachers being concerned about the trivialisation of mathematical reasoning (3), for example:

> Curriculum may lack quantity if meaning is not required.

The other common negative theme was fear of change (3). One teacher felt that basic algebraic processes would become more difficult and another commented that:

> The more things change, the more they stay the same — just a tool.

Summary

In summary, it was clear that the mathematics teachers participating in the research study were generally optimistic about the effects that CAS calculators would have on their teaching, on student learning, and on the curriculum. There were some dissenting voices, particularly among teachers in the 35–45 age range. There was little difference in views among male and female teachers.

Implications of the findings from the two research studies

The findings of Research Study 2 provide an optimistic portrait of Victorian mathematics teachers' perspectives on the potential effects of the mandated use of CAS calculators for grade 12 (VCE) mathematics courses in the near future. These teachers are highly experienced with the use of graphics calculators, which have been compulsory in VCE mathematics subjects for some time. Perhaps the initial hurdle was mastering the graphics calculator and its use is now totally integrated into their mathematics pedagogy; it is likely that the next step of introducing CAS to the classroom holds little threat or fear for the majority. The teachers were not directly asked whether they felt that any students would be disadvantaged by the introduction of CAS calculators. Interestingly there were no mentions of equity considerations in their responses to the question posed about potential effects on student learning. Yet, the findings from Research Study 1 sound warning bells with respect to an apparent increase in the gender gap favouring males at the highest levels of achievement in VCE Mathematical Methods CAS compared to Mathematical Methods.

It was recognised that there were only small numbers of students involved in the Mathematical Methods CAS pilot study. In the coming years, however, these numbers will increase. In 2009, most VCE mathematics students will be required to use CAS calculators. Close monitoring of the achievements of males and females in mathematics courses in which CAS calculators are used must continue. The period in which CAS calculators and graphics calculators will be used in parallel Mathematical Methods courses in Victoria provides an ideal opportunity. As noted earlier, changes to the examination formats for Mathematical Methods and Mathematical Methods CAS will be in place from 2006. Forster and Mueller (2001) reported that girls performed better than boys on examination questions that required algebraic calculations by hand. There is, therefore, the possibility that the calculator-free examination may serve to ameliorate the effects of apparent male advantage when CAS calculators are used that were found in Research Study 1. Should the expansion of the gender gap favouring males noted in Research Study 1 persist with widespread use of CAS calculators, there is a longer term threat to female participation rates in mathematics beyond compulsory schooling. While curricular and pedagogical changes are likely to be the focus of research into the use of CAS calculators, gender and other equity considerations must not

be ignored if technological advances are to contribute to fostering the mathematical understanding and potential of all students.

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Classroom notes